Effects of Milling on Functional Properties of Rice Flour

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ABSTRACT: A commercial long-grain rice flour (CRF) and the flours made by using a pin mill and the Udy mill from the same batch of broken second-head white long-grain rice were evaluated for their particle size and functional properties. The purpose of this study was to compare the commercial rice flour milling method to the pin and Udy milling methods used in our laboratory and pilot plant. The results showed that pin milled flour had more uniform particle size than the other 2 milled flours. The chalky kernels found in broken white milled rice were pulverized more into fines in both Udy milled flour and CRF than in the pin milled flour. The excessive amount of fines in flours affected their functional properties, for example, WSI and their potential usage in the novel foods such as rice breads (RB). The RB made from CRF collapsed more than loaves made from pin milled Cypress long-grain flours.

Keywords: functional properties, long-grain rice flour, novel foods

Introduction

Over half of the world's population uses rice as a staple food. In addition, rice has many unique functional properties, such as ease of digestion, white color, bland taste, and hypoallergenic properties. Nearly all rice cultivars are grown to be consumed as intact kernels. During milling, about one-third of white rice breaks. The broken rice usually sells at lower price than intact kernels. The broken rice is classed as second-head milled rice, screening milled rice, or brewers milled rice, based on the size of broken kernels (USDA 1977).

Rice is grown for its eating qualities as cooked rice. Therefore, literally hundreds of varieties of rice are grown all over the world for their unique characteristics. In the United States, specific chemical and physical criteria are used to describe the cooking and processing qualities of various cultivars (Webb 1985). These criteria are based on extensive physicochemical studies, which when taken together serve as indices of cooking, processing behavior, and standards such as long-, medium-, and short-grain rice. Amylose and protein contents of rice are considered to be the 2 most important criteria for eating qualities of rice (Webb 1985; Moldenhaur and others 2004).

In recent years, rice, especially rice flour, because of its unique functional properties, is being used in increasing numbers of novel foods such as tortillas, beverages, processed meats, puddings, salad dressing, and gluten-free breads (Kadan and Ziegler 1989; McCue 1997; Kadan and others 2001). These novel foods usually require rice flours having known amylose and protein contents (Kadan and others 1997). A commonly available commercial rice flour (CRF) was made by proprietary milling method from white second-head broken long grains. The broken rice is usually a mixture of several long-grain varieties (Moldenhaur and others 2004) and also varying amounts of thin and immature kernels. The product description of CRF has few specifications for proximate composition and gives only ranges of amounts of amylose or protein contents. This flour was recently evaluated in our laboratories to make whole rice bread (WRB), and even though it had amylose and protein contents similar to flour made in our laboratory by pin and Udy milling of the same second-head long-grain rice, it produced WRB with a lower specific volume and undesirable texture. This study was therefore undertaken to see if the differences in the baking performance of CRF compared to rice flours milled in our laboratory and pilot plant resulted from changes in the functional properties of the rice flours.

Materials and Methods

Rice flours

CRF was milled from second-head long-grain milled rice. According to commercial processors, CRF was milled by a proprietary method using a combination of a hammer mill, 1st pass and a turbo mill, 2nd pass. The second-head long-grain rice was also milled using an Alpine160 Z Kallplex (pin mill) at 11500 rpm (Augsburg, Germany) and a Udy Cyclone mill, using 0.5 mm screen (Udy Corp., Fort Collins, Colo., U.S.A.) in our laboratories.

The rice flours were analyzed for moisture, protein, lipid, and amylose contents (Kadan and others 1997; AACC 2000). Moisture was determined by the oven drying method (Horwitz 2000). Protein contents (Nx5.95) were determined by the combustion method using a nitrogen analyzer (Tru-Spec N, Leico, St. Joseph, Mo., U.S.A.). Amylose was determined by the simplified assay method developed by Juliano (1971).

Particle size determination and microscopy

The particle sizes of the milled rice flours were determined using a Beckman-Coulter LS particle analyzer (San Jose, Calif., U.S.A.). A 15% suspension of 3 milled flours in absolute ethanol (100%) was entered dropwise to the analyzer until the proper concentration was achieved.

For determining scanning electron micrographs (SEM), the above-mentioned suspension was dispersed on standard SEM

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stubs and allowed to dry. The material was coated with 200 to 3000 nm of gold/palladium, 60%/40% in a Humer II sputter coater (Technics, Alexandria, Va., U.S.A.). Images were taken on a FEL-Philips XL-30 environmental scanning electron microscope (Sunnyvale, Calif., U.S.A.) at 10 kv under high-pressure vacuum conditions.

Functional properties

The viscosity, water absorption index (WAI), and water solubility index (WSI) of the 3 flours were measured by the methods of Bryant and others (2001) and Kadan and others (2003). Two-and-a-half grams of each sample were suspended in 30 mL of distilled water (30 °C) in a 50-mL preweighed centrifuge tube by vortexing. The tubes were place in a water bath at 30 °C and stirred intermittently for 30 min. The suspension was centrifuged for 10 min at $3000 \times g$. The supernatant was decanted into a preweighed 50-mL beaker. The weight of the precipitate was used to calculate the WAI, which was reported as a ratio of weight gain divided by the weight of the sample (on dry weight basis). The supernatant from the WAI was dried at 95 °C and the weight of dried solids was used to calculate the WSI.

Viscosity was determined using a rapid visco analyzer (RVA) Model 3R (Newport Scientific, Eden Prairie, Minn., U.S.A.) and Thermocline for Windows software, Method 61-02 (AACC 2000). Sample (3 g based on 12% moisture) was added to 25 mL of water. The mixture was heated to 50 °C for 1 min and then ramped to 95 °C at a rate of 11.84 °C/min. After holding at 95 °C for 2.5 min, the temperature was decreased to 50 °C and held for 1.4 min. The mixture was constantly stirred and the total run time was 12.5 min. Viscosity was measured in RVA units (1 RVA unit = 12 Centa Poise [Cp]).

Figure 1 — Photograph of second-head long-grain milled rice.

Thermal properties were determined using differential scanning calorimetery (DSC) Model 4100 (Calorimetry Science Corp., Spanish Fork, Utah, U.S.A.). The system includes a reference cell and 3 sample cells. Two milligrams of rice flour and 3 mg of deionized water (1:1.5 or 33% solids) were placed in a Hastelloy ampule and subjected to 1 heating cycle. The samples were heated from 20 to 110 °C at a rate of 1.5 °C/min. Baseline subtractions were made on thermal curves. Thermal curves depicting starch gelatinization were characterized by 3 gelatinization temperatures: T_0 (onset of peak development, peak temperature), Tp (maximum heat flow reached during the scanning cycle and conclusion), and Tc (taken at the conclusion of peak development). The enthalpy associated with starch gelatinization (ΔH) was determined by drawing a line between T_0 and Tc and determining the area under curve. It is expressed as joule/gram of dry weight basis of rice flour basis. All samples were analyzed in triplicate. The breakdown viscosity was computed by subtracting the trough viscosity from the peak viscosity. Setback-1 was computed by subtracting peak viscosity from the final viscosity and Setback-2 was computed by subtracting trough viscosity from the final viscosity.

Whole rice bread (WRB)

The WRB was made using the method described by Kadan and others (2001) and Kadan and Schluckebier (2007). The ingredients rice flour, defatted bran, sugar, rice bran oil, salt, methocel K4M, yeast, and water (233.0, 12.0, 30.0, 14.0, 2.6, 4.7, 5.1, and 256.0 g, respectively) were mixed as follows. The dry ingredients were mixed thoroughly in a beaker. A water/rice bran oil mixture was heated to 42 °C to melt the oil completely. The heated water/oil mixture was placed into baking pan of a Welbilt bread machine (Appliance Co. of America, LLC, Great Neck, N.Y., U.S.A.), then the dry mixture was added slowly, and stirred with a spatula. The mixture was kneaded manually for 10 min and the "custom program" started. The time-temperature combination of each baking step was followed as reported by Kadan and Schluckebier (2007). After having the baking cycle completed (2 h and 50 min), the pan with bread was removed and allowed to cool to room temperature for 30 min. The specific volume was determined by the rapeseed displacement method (Kadan and others 2001).

Results and Discussion

According to commercial processors, intact second-head long-grain rice CRF can be a mixture of several long-grain rice cultivars depending upon the location of the rice mill and the rice cultivars processed (Moldenhaur and others 2004) at that time. The analysis of the second-head broken kernels was found to have

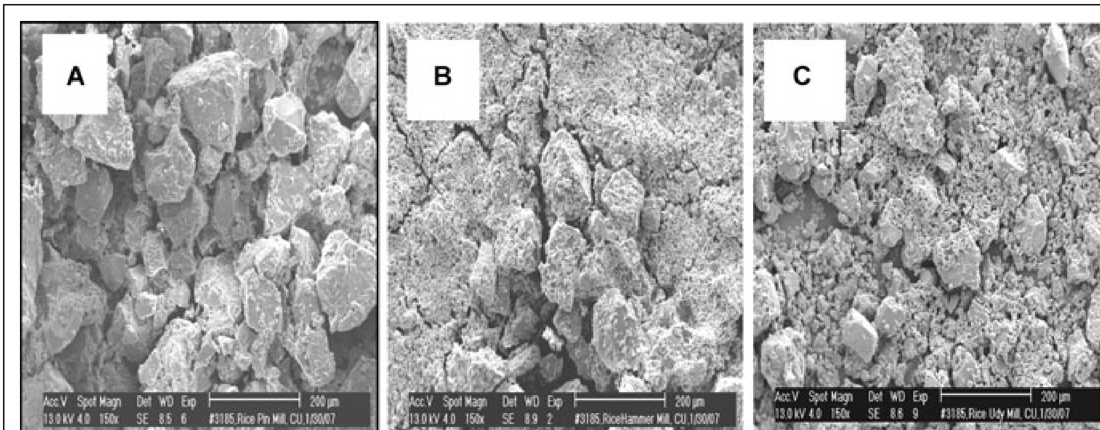

Figure 2 — SEM 150× of second-head milled rice flour (A) pin mill, (B) CRF, and (C) Udy mill.

23.9% amylose, 8.0% protein, 0.55% lipid, and 11.86% moisture, indicating that the values for protein, lipids, and moisture levels were comparable to flours made from the cultivar Cypress, which produced several acceptable novel rice foods (Kadan and others 2001, 2003; Kadan and Schluckebier 2007). However, the amylose content of CRF was about 3% higher than Cypress long-grain flours (23.9% compared with 20.7%). In our earlier studies, high-amylose rice flours (> 22.0%) did not produce acceptable WRB (Kadan and others 2001).

The photograph of the broken rice to produce CRF is shown in Figure 1. It shows a mixture of mature (translucent) and immature (chalky) rice and perhaps some weed artifact (reddish color). On close examination, all the immature kernels were smaller in size than the mature kernels and most kernels had some chalkiness (white belly). Chalkiness is an undesirable trait for practically all forms of rice because of nonuniformity produced in rice flours from batch to batch (Webb 1985; Lisle and others 2000). The chalky kernels from this batch of broken long-grain kernels weighed approximately 10% less than the mature kernels.

The SEM of pin (A), CRF (B), and Udy (C) milled rice flours at 150× is shown in Figure 2. Both CRF and Udy milled flours appeared to have many more fine particles than the pin mill samples. It is suggested that most of the fines are formed from the chalky kernels, which are soft, weigh less, and are probably less crystalline and thus pulverize more easily into fines. Harsh milling conditions may also cause some damage in the starch moiety of the flour. The Kaloplex pin mill, on the other hand, produced fewer fines and with more particles of uniform size.

Table 1 — Particle size second-head milled rice flours.

	Mean (μm)	Median (μm)	Mode (μm)
Pin mill rep1	170.2	142.5	168.8
Pin mill rep2	156.2	131.7	153.8
Pin mill rep3	185.7	152.3	168.8
Pin mill rep4	150.7	133.0	153.8
Average	165.7 ± 15.7	139.9 ± 9.6	161.3 ± 8.7
CRF mill rep1	163.4	157.9	245.2
CRF mill rep2	162.9	159.0	245.2
CRF mill rep3	169.1	169.0	269.2
Average	165.1 ± 3.4	161.9 ± 6.1	253.2 ± 13.8
Udy mill rep1	124.5	91.66	245.2
Udy mill rep2	155.1	136.2	203.5
Udy mill rep3	165.4	150.2	203.5
Average	148.3 ± 21.3	126.0 ± 30.6	217.4 ± 24.1

Table 2 — Water absorption index (WAI), water solubility index (WSI), and differential scanning calorimetric (DSC) values (n = 3) of rice flours.

Rice flours	WAI	WSI	DSC Peak temp °C	DSC ΔH kJ/g
CRF	1.0 ± 0.0	1.43 ± 0.02B	83.3 ± 0.14A	93.3 ± 2.55A
Pin mill	1.0 ± 0.0	1.31 ± 0.01C	79.7 ± 0.14B	86.9 ± 5.30AB
Udy mill	1.0 ± 0.0	1.52 ± 0.00A	79.9 ± 0.21B	84.3 ± 4.10B

Means that do not share a common letter differ at $P < 0.10$.

The particle sizes of the 3 flours determined by the Coulter LS particle analyzer are shown in Table 1. The mean particle sizes of the 3 flours were comparable but the median size for CRF and the mode values (most frequent value by a random variable) was higher in CRF and Udy milled flours than pin milled flour. The chalky kernels, being softer, do not break into uniform sizes under Udy and double milling of CRF. The SEM pictures of CRF (B) and Udy milled (C) showed more fines on the surface than the pin milled (A) flours. The can be explained as ratio of mode against medium particle size being much higher (1.56 and 1.75, respectively) in samples B and C than in sample A (1.15), suggesting the larger particles in samples B and C settled faster than those in sample A. Thus, the larger particles in samples B and C get buried at the bottom, whereas pin milled flour settled uniformly, and hence there were few fines at the top. This suggests that electron micrographs cannot be used to measure particle sizes. A uniform and specific particle size flour was found to yield consistent rice bread (Kadan and Schluckebier 2007).

The WAI, WSI, and DSC values are shown in Table 2. The WAI was identical in all 3 rice flours, but WSI and DSC values differed. The lower values of WSI for pin milled flour are probably due to fewer fines and uniform particle size flour, which will be expected to absorb less water. The ΔH for pin milled is lower than CRF and slightly higher than Udy milled flour.

The RVA viscosity parameters of the 3 rice flours are shown in Table 3. The CRF had higher peak viscosity, trough, final viscosity, and breakdown viscosity than pin and Udy milled flours. No suitable explanation can be given except that CRF had a higher mode than the other flours. It may be that the larger particle size took longer and higher temperatures to gelatinize and imparted higher viscosities than smaller particle sizes (Table 1). The particle sizes can affect the RVA (Bryant and others 2001).

The rice flours were also used to make WRB, and their specific volumes are given in Table 4. The Udy milled flour had lower specific volume than the other 2 flours. However, all the breads had lower specific volume as compared with the WRB made from pin milled Cypress rice flour from previous studies (Kadan and Schluckebier 2007) and undesirable texture, particularly in RB made from CRF and Udy milled flours (large holes in the slices). The main reason is probably the large amounts of thin, immature, and chalky kernels in second-head broken rice (Marshall 1992) and high amylose contents (Kadan and others 2001; Kadan and Schluckebier 2007). It may be possible that some suitable additives and techniques, for example, addition of wax rice (very low amylase) and food gums, can improve the baking properties of CRF.

Conclusions

The milling methods have important effects on the functional properties of rice flour and hence their usage in novel foods. The current method used to make CRF apparently does not produce flour of uniform particle size. The problem is further exacerbated by the presence of thin and immature kernels in the second-head long-grain milled rice. The thin and immature kernels, which are less dense, lighter, and probably softer than mature

Table 3 — Parameters of rice flours cooking properties measured by RVA.[a,b]

Rice flours	Peak viscosity	Trough	Final viscosity	Breakdown viscosity	Setback-1	Setback-2
CRF	258.68 ± 0.75	143.43 ± 0.96	301.40 ± 1.00	107.25	157.96	50.71
Pin mill	212.04 ± 0.18	115.67 ± 0.46	267.40 ± 0.38	96.96	151.35	54.77
Udy mill	211.04 ± 0.04	114.86 ± 0.46	257.61 ± 0.42	96.19	142.76	46.65

[a]Average of 3 individual determination.
[b]Viscosity in RVA: 1 RVA = 12 Cp.

Table 4—Specific volume (mL/g) of rice bread volume/weight.

Specific volume		
CRF	Pin	Udy
3.407	3.312	2.950
3.998	3.882	3.283
4.013	3.906	3.056
Average 3.806 ± 0.28	3.700 ± 0.27	3.096 ± 0.139

kernels, disintegrate easily into fines as shown by SEM. The pin mill imparts more uniform particle size and therefore is more suitable for developing novel rice foods. Different cultivar mixtures may yield different results depending upon the amounts of chalkiness, maturity, and other characteristics.

The functional properties of CRF flour can perhaps be further improved by removing immature kernels and using a known source of broken long-grain rice and thus specifying its important biochemical properties such as amylose, protein, and lipids contents. The flours made from high amounts of immature, chalky kernels can be used in products like pancakes and cookies and mature kernels can be used in breads.

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